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SHOCK AND VIBRATION PERFORMANCE OF AN EPOXY CHOCKING COMPOUND.(U)

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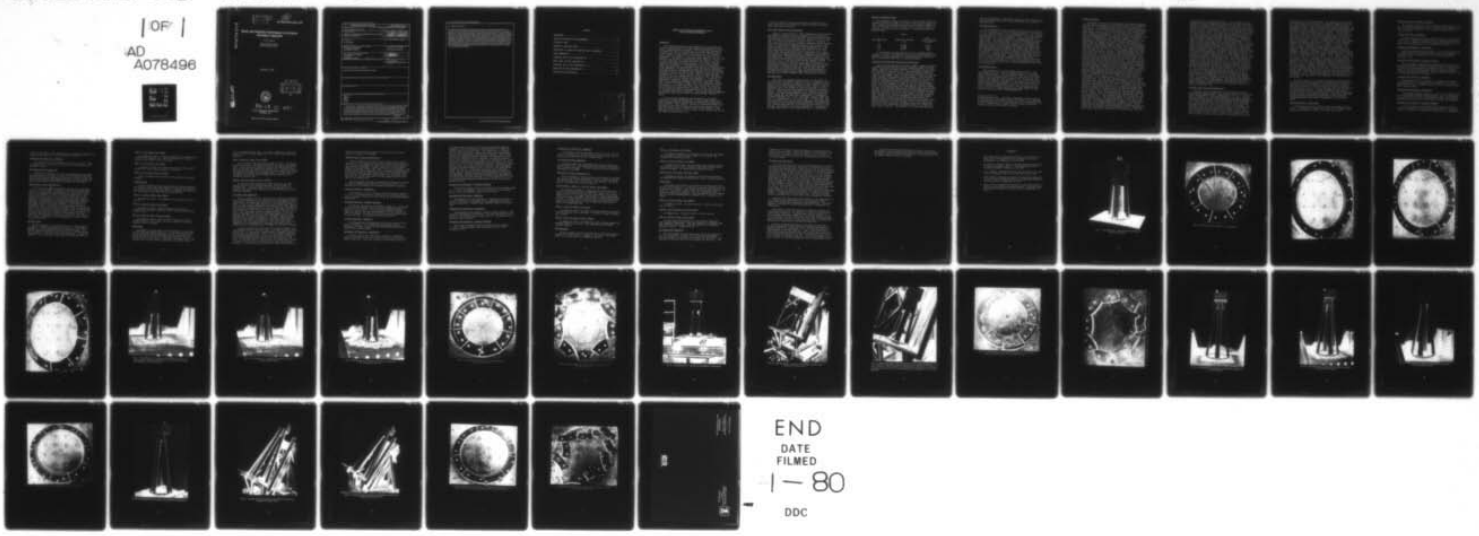

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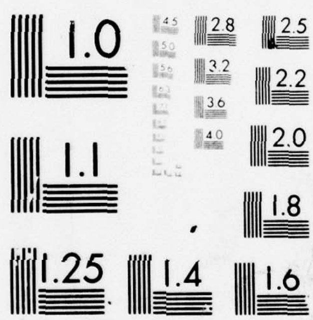
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Shock and Vibration Performance of an Epoxy Chocking Compound

E. W. CLEMENTS

Applied Mechanics Branch
Ocean Technology Division

December 7, 1979

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For some years, various epoxy compounds have been used to form machinery/equipment chocks on merchant ships. In application, the item to be mounted is located and aligned, and supported in place by some temporary means while the chocking compound is mixed and poured in place. The advantages are speed, economy and intimacy of fit compared to conventional methods. More recently, these compounds have been used to a limited extent on Navy combatants, where shock and vibration environments are much more severe than those encountered in the mercantile fleet.

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20. Abstract (Continued)

In order to evaluate the ability of poured epoxy chocks to withstand these environments, two structures have been constructed which resemble equipment items which have been so mounted on combatants in terms of mounting footprint, weight and overturning moment. These have been subjected to shock and vibration tests similar to those required by the Navy for acceptance of shipboard equipment. The epoxy chocks were unaffected by the vibration test, while under shock test they sustained minor cracking and spalling, but without significant reduction of load-bearing area and no impairment of alignment function. It was concluded that their performance was satisfactory for the test situations employed. It should be cautioned, however, that other environmental factors (temperature, humidity, contaminants, etc.) than those considered here may also be effective, and that other mechanical situations might modify the results observed. Such factors should be evaluated for any contemplated installation.

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SHOCK AND VIBRATION PERFORMANCE OF AN EPOXY CHOCKING COMPOUND

Background

Much shipboard machinery and equipment must be installed with chocks, usually because of critical alignment requirements or uneven and/or incompatible mating surfaces. The conventional procedure is to support the item in its final location by some temporary means, insert several (or many) metal blocks, shim stock, etc. between it and the surface to which it is to be attached, and fasten it down permanently. The process is relatively time-consuming, laborious, and expensive, particularly if machined blocks are required. In use, it is often found that such chocks eventually work loose, sometimes requiring realignment and reinstallation. At the least, regular inspection is required. In the mercantile fleet, for some years epoxy compounds of various proprietary formulations have beem employed as an alternative. To install epoxy chocks, the item is temporarily supported as before, damming material inserted to bound the locations selected for the chocks, and the epoxy compound mixed and poured into the dammed areas as a viscous liquid. After the chocks have been allowed to set for an appropriate period,(about a day), the dams are removed and the item is fastened down permanently. In addition to advantages of speed and economy of installation, the epoxy chocks have two main mechanical advantages over conventional metal chocks: first, since it is poured in place, there is an intimate fit between the surfaces of the chock and those of the item and the mounting structure over the entire area of the chock; second, the total area of the chocks may extend as far as desired up to the total area of the item-mounting structure interface. These latter factors compensate for the much lower elastic modulus of epoxy materials relative to metals.

In view of these advantages and the generally satisfactory experience of mercantile application, in recent years limited use of epoxy chocking compounds has been made in installations aboard some Navy combatants. Here, however, the service environments differ both qualitatively and quantitatively from those of the merchant fleet. Combatants must be able to operate at high speeds, perhaps in rough seas, for extended periods, and are likely to shoot and be shot at, and

Note: Manuscript submitted October 5, 1979.

so exhibit shipboard vibration environments substantially more severe than those of the mercantile world, and shock environments which there are non-existent.

Shock and Vibration Test Requirements

Because of the existence of severe shipboard shock and vibration environments, equipment and system components to be installed on Navy ships are required to pass stringent shock and vibration tests. The procedures and criteria for these are spelled out in MIL-S-901C (Ref. 1) (shock) and MIL-STD-167-1 Type I (Ref. 2) (vibration). These specified tests are not intended to represent the environments found in any particular shipboard situation, but are more of the nature of proof tests, as experience has demonstrated that items which have passed these tests rarely give problems in the fleet, while those which do give problems rarely pass the tests. For shock tests, the specification (ref. 1) prescribes one of several test machines and operating procedures, depending on the weight of the tested item. These machines are described in Reference 3; the one employed for the tests of the epoxy chocking compound was the Navy Class HI Shock Machine for Mediumweight Equipments (MWSM). For vibration tests, on the other hand, the specification (Ref. 2) prescribes a regimen of vibration amplitudes and frequencies to be maintained at the mounting point of the tested item: any machine may be used, so long as the required vibration amplitudes and frequencies are supplied to the item. The machine employed for the tests of the epoxy chocking compound was the NRL 5,000-lb Reaction-Drive Vibration Machine (RVM), described briefly below.

Auxiliary Tests

Since Navy ships operate from the tropics to the poles, the possible effect of operating temperatures on the performance of the epoxy chocking compound is a matter of concern. However, the test machines at the Naval Research Laboratory (NRL) Shock & Vibration Laboratory (S & V Lab) operate at the building ambient, so that a series of auxiliary tests were conducted to evaluate temperature effects. These tests were performed by the Nonmetallic Materials Branch of the Naval Surface Weapons Center, White Oak Laboratory, Silver Spring, MD, and consisted of measurements of compressive strength (ASTM D695, Ref. 4) and Izod impact strength (ASTM D256, Ref. 5) at temperatures of -40, 70 and 120F. In these tests, NSWC was furnished a quantity of the epoxy components, which were mixed, poured and cured in accordance with manufacturer's recommendations. Test specimens were machined to ASTM specifications from the cured material, and tested at the various temperatures. The effects of prolonged maintenance at test temperature were not investigated.

Results of Auxiliary Tests

The compressive strength was found to vary relatively little with temperature, being 10% lower at 120F then at 70F, and 10% higher at -40F. Somewhat more variation was noted at Izod impact strength, the value at -40 being 20% lower than that at 70F, but still a quite respectable value for this sort of material. The measured values are given in Table I.

Table I

Test Temperature F	Compressive Strength psi	Izod Impact Strength ft-lb/in
-40	24,060	0.331
70	22,680	0.417
120	20,750	0.408

As the material was mixed and cast in air, a somewhat porous structure was noted. The porosity could be reduced by vacuum-casting, probably with some enhancement of the measured strength values, but this is not done in normal use of chocking compounds.

Description of Shock and Vibration Test Structures

Two test structures were built which roughly resembled equipment items that have been installed on Navy combatant vessels with epoxy chocks. Each test structure consisted of a mounting ring and a mass lump connected by four legs of car - building channel, constructed as an all steel weldment. The test structures resembled the real items in total weight, height of center-of-gravity above the mounting plane, mounting configuration and chock geometry. Some extra features were added in order to extract more information from the test results. The mounting rings were flame-cut from as-rolled 3/4 - in. plate and drilled through with clearance holes for the hold-down bolts. No other machining was done, so that the mounting surfaces mating to the chock material were rough-textured, wavy from welding the legs to the mounting rings and had irregular edges from the flame cutting. The bolt holes around one-half of each mounting ring were spaced on the center line of the ring, while those around the other half were located on a circle one bolt diameter in from the outside edge. Because of the four-leg arrangement, the inertial loading pattern of each structure was strongly non-uniform around its mounting ring, and each structure was expected to show a first horizontal resonance in the 16-25 Hz range. This is the range of frequencies in which the highest acceleration inputs are imposed on a test item by the standard Navy shipboard vibration test (MIL-STD-167-1, Type I) (Ref. 2). The response of the test structures them-

selves were determined by exploratory vibration tests without chocks, where the mounting rings were bolted down solidly by a 3/4 inch mounting plate.

Test Structure No. 1

The total weight of this structure is 920 lb, and its center of gravity is located 37 in. above its mounting surface. Its legs are 4 in. car building channel, and its mounting ring 2-3/4 in. wide with an inner radius of 6-3/4 in. Eighteen 21/32 in. dia. holes provide clearance for 5/8 - 11 hold down bolts. Test Structure No. 1 is shown in Fig. 1 just after removal of the damming material from the cured chocks. Its overall height is 47-1/2 in. from the mounting plate to the top of the mass lump. Because of its symmetry, the directions chosen for horizontal vibration tests were those which directed the vibration axis through two opposite legs ("Horizontal 90°") and between pairs of adjacent legs ("Horizontal 45°"). For the exploratory vibration tests to determine the characteristics of Structure No. 1 itself, the mounting ring was bolted down directly to the 3/4 in. mounting plate. In the vertical direction, a resonance was found at 39 Hz with a Transmissibility Ratio (TR)* of 1.05:1. In both horizontal directions a first resonance was found at 13.5 Hz, with TR of about 4:1. Principle resonances were found at 23 Hz for Horizontal 45° and 25 Hz for Horizontal 90°, with TR of 10:1 in each case.

Test Structure No. 2

Test Structure No. 2 is an enlarged version of No. 1. Its total weight is 1675 lb, and its center of gravity is 81 inches above mounting surface. Its legs are made from 6 in. car-building channel, and its mounting ring is 3-1/2 in. wide with 14 in. inner radius. Clearance holes for the eighteen 3/4 - 10 hold down bolts are 25/32 in. diameter. Structure No. 2 is shown in Fig. 16, with overall height from mounting plate to top-of-mass lump of 90-3/4 in. Vertical resonances were found at 25 Hz, TR 1.3:1, and 47 Hz, TR 1.6:1. For both horizontal directions, first resonance was found at 14 Hz, TR 4.5:1. Major resonances were 25 Hz, TR10:1 for Horizontal 45° and 27 Hz, TR 8:1 for Horizontal 90°.

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*Transmissibility Ratio: the ratio of amplitude of motion measured at the mass lump in the nominal direction of motion to the amplitude of motion measured at the test machine table in the nominal direction of motion without regard to phase, spectral purity, or possible motion in directions other than the nominal.

Chock Preparation

The chocks for the two Test Structures were prepared following the same general procedure, but at different times, as all testing of Structure No. 1 was completed before the chocks of Structure No. 2 were poured. All preparations took place in a lab space temperature-controlled to 74 $\pm$ 2 F. All tools and materials were placed in this space several days previously so that they would come to temperature before assembly and preparation. The procedure was in accordance with the recommendations of, and made use of tools and materials supplied by, the manufacturer of the chocking compound. The latter consisted of a mixing tool, and a spray-on mold release agent. The mold release was sprayed on all metal surfaces which would be in contact with the chocking compound - the top of the mounting plate, the bottom of the mounting ring, the inner sides of the circumferential dams, and the sides of the spacer bars. The spacer bars were steel bar stock 3/4 in. X 1/4 in., cut in lengths equal to the width of the mounting ring plus 1/2 inch. They were machined with a few mils taper to the 1/4 in. dimension to facilitate removal after the chocks had cured. For each test structure, nine spacer bars were laid on edge on the mounting plate so that they were radial to the mounting ring when the test structure was set down on them, with two hold-down bolt holes between each pair of bars. The test structure was then rested on them, and the hold-down bolts passed through the clearance holes in the mounting ring and threaded into the mounting plate and tightened securely, but to no particular torque. In the 3/4 in. region where the bolts would be in contact with the chocking compound, their threads were filled out to body diameter with non-melt silicone grease and fitted with lengths of thin-wall Teflon tubing. Circumferential dams were formed from strips of 1/16 in. sheet metal 1-1/4 in. wide. One of these was pressed against a circumference of the mounting ring, to which the end of the spacer bars were flush. The other was tightened against the other ends of the spacer bars, which protruded 1/2 in. beyond the other circumference of the mounting ring. The overall arrangement, for each test structure, formed nine chock pads 3/4 in. thick which completely supported the mounting ring save for 1/4 in. separation between pads. Each pad contained two hold-down bolts, and had an overpour space 1/2 in. wide by 1/2 in. high to ensure that the pad volume was completely filled. Due to the overpour space, each pad had a segment 1/2 in. wide and 1-1/4 in. high outside its load-bearing area. For Test Structure No. 1, these overpour regions were on the outer side of the mounting ring. For Test Structure No. 2, they were on the inner side to bring the hold-down bolts closer to the edge of each chock pad. The chocking compound was furnished on a two-component (filled epoxy and hardener) system in one-gallon units. One of these units was mixed and poured immediately, then another mixed and poured until the dammed volume was completely filled. Mixing was done using a mixing tool, furnished by the manufacturer, and held in

a low-speed (200 rpm nominal) hand-drill. After pouring, the test assemblies were left untouched for seven days, and were then disassembled for inspection and photography of the chock pads. The test structure was lifted off the chock pads, the spacer bars were slipped out and the chock pads separated by cutting the overpour ring with a bandsaw. Figure 2 shows the chock pads of Test Structure No. 1 after they had been cut apart. Each chock pad was numbered and referenced to fiducial markers on both mounting ring and mounting plate, so that throughout this and subsequent disassemblies and reassemblies each pad remained between the proper mating surfaces. Several features of Figure 2 are worth noting. The bearing surfaces of the chocks are quite rough and porous, and show several voids. The surfaces of the overpour regions, on the other hand, are smooth, implying little lateral mobility of bubbles of entrained air or evolved gas. Figure 3 shows the chock pads of Test Structure No. 2 after disassembly, and Figure 4 the top and Figure 5 the bottom surfaces of the chock pads after separation. The general appearance is much the same as that of the pads for Structure No. 1. After inspection and photography, the test assemblies were put back together and the hold-down bolts tightened to the desired torque. The static bearing load on the chock pads due to the weights of the test structures were negligible, only a few psi in either case. A total static load of 700 psi was chosen as the middle of the range of static load recommended by manufacturer, and the bolt torque required to produce the necessary bolt tension calculated and rounded. For test Structure No. 1, it was 50 ft. lb. and for Test Structure No. 2, it was 150 ft. lb. Calculated total bearing loads were 714 psi and 715 psi respectively. The mounting ring/chock pad was felt likely to be fairly flexible in comparison to the bolt stiffness, so that the total bolt load could approach the sum of the static and dynamic loads. Accordingly, hex-socket cap screws were used for hold-down bolts because of their high strength. The completed assemblies were then transferred to the NRL Shock and Vibration Lab, where the ambient temperature varied from 80 - 90 F during the period of the shock and vibration tests.

Vibration Tests of Test Structure No. 1

Vibration tests were conducted on the NRL 5000-lb Reaction-Drive Vibration Machine (RVM). This machine consists of a rigid test table weighing 6000 lb with a mounting area of 7 x 5 ft. The test table is supported by a cantilever spring at each corner, allowing free motion vertically and in the horizontal direction perpendicular to the axes of the springs - the long dimension of the test table lies in this direction - and very little motion in the orthogonal horizontal direction, which is along the axes of the springs. At each end of the test table is a vertical structure to which an NRL Three-Mass Reactive Force Generator is fastened. Each of these contains three rotating eccentric weights whose relative positions can be changed to control both the direction and amplitude of the motion of the test table, which is due to the reaction forces from

the imbalance of the rotating weights. The generators can be raised or lowered along the end structures to align the reaction forces with the center of gravity of the test table/equipment combination for horizontal vibration. Tests were conducted in general accordance with MIL-STD-167-1, Type I (Ref. 2), which is the general specification for vibration testing of equipment for Navy vessels. The specification calls for vibration over the frequency range of 4 - 50 Hz in three orthogonal directions corresponding to the vertical, athwartship and fore - and - aft orientations of the equipment item as it would be installed aboard ship. For each of these directions, the test consists of three parts. The first is "Exploratory", where the vibration frequency is smoothly varied from 4 - 50 Hz with a table excursion (Peak-to-peak displacement) of 0.20 in. from 4 - 33 Hz and .006 in. from 34 - 50 Hz. The purpose of this segment of the test is to reveal resonances and give a general feel for the dynamics of the equipment. The second segment is "Variable Frequency", where the vibration frequency is increased in 1 Hz increments and each integral frequency is maintained for five minutes. Table excursion is .060 in. in the 4 - 15 Hz range, .040 in. for 16 - 25 Hz, .020 in. for 26 - 33 Hz, .010 in. for 34 - 40 Hz, and .006 in. for 41 - 50 Hz. Because of the greater excursion, resonances are sometimes found during this segment of the test which escaped notice during the Exploratory test. The final part of the test is "Endurance", where the vibration frequency is tuned to equipment resonance and maintained for a total of two hours minimum. Usually, there will be a principal resonance, so the full two hours dwell time is spent here. If two or more resonances of about equal importance are found, the two hours may be divided between them. If no resonance was found, the two hours are put in at a frequency of 50 Hz. Test table excursion at any frequency is to be the same as that specified for that frequency for the Variable Frequency test.

As noted above, the two horizontal directions "Horizontal 90°" and "Horizontal 45°" were chosen for test rather than the orthogonal directions, due to the symmetry of the Test Structures. Figure 6 shows Test Structure No. 1 mounted on the test table oriented for the Vertical test, Figure 7 for the Horizontal 90° test, and Figure 8 for the Horizontal 45° test. Motion was measured with velocity pickups bolted to the top of the mass lump of the test structure and to the test table of the vibration machine. The pickup outputs were fed into matching integrating vibration meters which give dial readings indicating peak-to-peak displacement of the associated pickup.

Vertical Direction - Exploratory

The exploratory test was conducted over the frequency range 5 - 40 Hz. No substantial resonance was located, but a gradual, smooth increase in TR starting at 13 Hz. At 40 Hz, TR was 2.0:1.

Vertical Direction - Variable Frequency

The variable frequency test was conducted over the range 5 - 33 Hz. As during the exploratory test, no resonance was located, but TR began to increase slightly at 13 Hz, reaching a maximum value of 1.5:1 at 33 Hz.

Vertical Direction - Endurance

The RVM was operated at 33 Hz, excursion 0.0195 in. for a period of two hours. During the final half hour, TR slowly increased from 1.5:1 to 1.6:1. However, all mounting bolts were found to have maintained their original torque at the conclusion of the test.

Horizontal 90° Direction - Exploratory

The RVM was operated over the range 5 - 25 Hz. The TR was found to increase above 7 Hz, increasing more rapidly as the frequency increased. At 25 Hz, TR was 8.1:1, and a strong resonance was located at 26 Hz.

Horizontal 90° Direction - Variable Frequency

With the greater table excursion, the motion of the test structure was more extreme, although the behavior of TR with frequency was the same as that noted during the Exploratory test. At 24 Hz, the motion of the test structure's mass lump was judged unacceptably large, and the test was terminated. The test frequency range was then 5 - 23 Hz, and the TR at 23 Hz was 4.5:1.

Horizontal 90° Direction - Endurance

The endurance test was conducted at a frequency of 23 Hz for a period of two hours. No change in TR was noted over this period. Following the test, all mounting bolts were found to have maintained their original torque.

Horizontal 45° Direction - Exploratory

The frequency sweep was started at 5 Hz; as in the Horizontal 90° test, an increase in TR was found starting at 7 Hz. In this direction, however, TR was found to increase more rapidly with frequency, reaching a value of 22.2:1 at 20 Hz, where the test was terminated.

Horizontal 45° Direction - Variable Frequency

As with the test in the Horizontal 90° direction, this test showed the same behavior of TR with frequency found in the Exploratory test. However, the higher table excursion led to unmanageable

motions of the mass at lower frequencies. The Variable Frequency test range was restricted to 5 - 18 Hz; at 18 Hz, TR was 6.1:1.

Horizontal 90° Direction - Endurance

The endurance test was conducted at 18 Hz for two hours. Again, no change in TR was noted over this period, and the mounting bolts maintained torque.

Post-Vibration Test Inspection

Following the vibration test, the test assembly was taken apart for inspection of the chocks. As may be seen in Figure 9 (top) and Figure 10 (bottom), no change was found in their condition, save that their bearing surfaces were somewhat grimier. The test assembly was then put back together and mounted on the MWSM for shock tests.

Shock Tests of Test Structure No. 1

For tests on the MWSM in accordance with the Navy requirements of Ref. 1, the test item is mounted on a flexible channel arrangement in its normal manner, and subjected to a group of three blows. This test arrangement is called the "Vertical Orientation", since the vertical axis of the item as installed aboard ship is also vertical in the test setup. Next, the test item on the flexible channels is rotated 30° so as to induce shock excitation along the axis which is athwartship in its shipboard installation, and an additional group of three blows delivered. If the item may be installed on ship so that either of its horizontal axes may be athwartship, then it is mounted on the MWSM so that each horizontal axis in turn is inclined, for a total of nine blows. Alternatively, the test item, without the flexible channels, may be mounted in the 30°-Corner Bulkhead, which inclines both horizontal axes simultaneously, and subjected to a group of three blows, for a total of six. Either of the inclined test arrangements is called the "30°-Inclined Orientation."

Vertical Shock

The test assembly of Test Structure No. 1 is shown mounted on the MWSM in the Vertical orientation in Figure 11. The flexible channels are visible immediately below the mounting plate. The Test Structure is oriented so that chock pad No. 1 and the adjacent ends of Pads No. 5 and 6 are closest to the channels. In this configuration, the total weight on the MWSM anvil table was 1820 lb.

Blow 1 - 1 ft. Drop, 3 in. Travel

No damage was noted. A slight loosening of the mounting bolts closest to the channels (i.e., those through Pad No. 1 and the adjacent ends of Pads 5 and 6) was found.

Blow 2 - 2 ft. Drop, 3 in. Travel

No damage was noted. The same bolts which loosened slightly during Blow 1 also loosened slightly on this blow.

Blow 3 - 2 ft. Drop, 1-1/2 in. Travel

Again, no damage could be found, but the same bolts loosened slightly.

Inclined Shock

The test assembly was then removed from the flexible channels and installed in the 30^{o}-Corner Bulkhead, oriented so that Pad No. 2 was closest to the corner. With this test configuration (Figure 12) the total weight on the MWSM anvil-table was 3669 lb.

Blow 4 - 1-3/4 ft. Drop, 3 in. Travel

No damage was noted. No loosening of the mounting bolts was detected.

Blow 5 - 2-3/4 ft. Drop, 3 in. Travel

No damage was noted. Slight loosening was noted in the mounting bolts passing through Pads 3 and 8, and the adjacent ends of Pads 4 and 7.

Blow 6 - 2-3/4 ft. Drop, 1-1/2 in. Travel

No damage was noted. Again the bolts listed above (Blow 5) loosened slightly. With Blow 6, the blow schedule of the specification test was completed.

Extra Blows

No damage to the chock pads of Test Structure No. 1 was found to result from the regular shock test. It was also desired to see how they performed when the mounting bolts were relatively loose, so that the Test Structure would have more opportunity to move around relative to the chocks. Accordingly, the mounting bolts were loosened, and tightened enough to grasp the lock-washers firmly

without compressing them fully. The torque required to do this was about 8 ft.-lb., vice the normal 50 ft.-lb. Blows 5 and 6 were then repeated.

Blow 7 - 2-3/4 ft. Drop, 3 in. Travel

It was observed that the overpour ridge of Pad No. 3 at the end adjacent to Pad No. 4 had moved outward from the edge of the mounting ring. Closer inspection revealed a crack in the bearing section of Pad 3 at this end just outside the mounting bolt. No similar crack was found at the other end of the pad, but as the overpour was visibly separated from the edge of the mounting ring for a third or more of its length, it would be safe to assume that the observed crack extended at least as far.

Blow 8 - 2-3/4 ft. Drop, 1-1/2 in. Travel

In this blow, the overpour and a small section of the load-bearing portion of Pad 3 slipped completely out from under the mounting ring. As shown in Figure 13, it slid down until it was stopped by the row of bolts used to attach the mounting plate to the 30^{o}-Corner Bulkhead.

Post-Shock Test Inspection

The test assembly was then removed from the MWSM and disassembled. The top and bottom views of the chocks are shown in Figures 14 and 15, respectively. As may be seen, the loss of the broken-off portion of Pad No. 3 did not entail much reduction in its load bearing area, and would not have impaired alignment of the mounted item. Note, however, that while the circumference of one bolt hole (the upper in Figure 14) is substantially intact, that of the other is about half gone. As it exists, this crack might allow the remaining portion of the pad to pivot on the upper bolt until its ends bound against those of the adjacent pads, which would cause little additional loss of bearing area and still no effect on alignment. A slightly different crack trajectory could easily have split both bolt holes, and perhaps allowed the pad to be lost completely. Given the overall chock configuration, it is questionable if even this event would lead to significant loss of bearing area or alignment in practical situations.

It should be noted that there can be no absolute certainty that the cracking of Pad No. 3 did not occur, or at least initially, on an earlier blow. A crack in that location would be extremely difficult to detect without disassembly. Blow 7, in the inclined orientation with loosened mounting bolts, was the first which would be likely to allow the separation of pieces which led to the detection of the crack. By the same token, it was the first blow which would be likely to cause such a crack, as the loosened bolts would allow the Test Structure to shift down the slope during the upward acceleration of

the anvil-table, causing the edge of the mounting ring to thrust against the ridge of the overpour.

Vibration Test of Test Structure No. 2

After completion of the tests of Test Structure No. 1, Test Structure No. 2 was assembled and chocks prepared as described above. After curing, the assembly was taken apart and the chocks removed, separated and photographed. Figure 3 shows the chock pads after removal of the Test Fixture, and Figure 4 their top and Figure 5 their bottom surfaces after separation. As may be seen, the appearance of the chocks is generally quite similar to that of the chocks of Test Structure No. 1: a generally porous surface with occasional voids. Here the more sizable voids seem to be more numerous per unit area than in the previous case.

The test assembly was then reassembled and installed on the RVM as shown in Figures 16 (Vertical) and 17 (Horizontal 90°). The mounting for the Horizontal 45° orientation is shown in Figure 18.

Vertical Direction - Exploratory

The exploratory test was conducted over the frequency range of 5 - 33 Hz. The TR was found to increase slowly with increasing frequency, reaching a value of 1.45:1 at 33 Hz, but no definite resonance was located.

Vertical Direction - Variable Frequency

The RVM was operated over the frequency range of 5 - 33 Hz, with the TR once more showing a slow rise with increasing frequency to a value of 1.46:1 at 33 Hz. As this test was performed following repairs to the RVM, the test was extended to 47 Hz to evaluate the RVM's performance. The slow rise in TR continued, reaching a value of 2.1:1 at 47 Hz. No definite resonance was located.

Vertical Direction - Endurance

The endurance test was performed at 33 Hz for a period of two hours. The TR was 1.4:1, and did not change during the test. Following the test, it was found that the mounting bolts had maintained their original torque.

Horizontal 90° Direction - Exploratory

As noted earlier, the test table of the RVM is constrained against motion in one axis, but is free to move in the plane orthogonal to that axis. The axis of motion in that plane is selected

by adjusting the direction of the reaction forces from the force generators, with due attention to the distrubutions of weight and reaction forces of the test item. Test Structure No. 2, however, with its very high center of gravity and large overturning moment, requires more compensation than the RVM can provide. Tests in the horizontal orientations featured substantial rocking motion, principally at low frequencies and at resonance. The behavior pattern found on the exploratory test was that at low frequencies (5 - 12 Hz) the motion of the mass was considerably less than that of the table (TR at 5 Hz, 0.2:1) as the RVM and Test Structure combination rotated about on axis fairly high on the Test Structure. As the frequency increased, this motion smoothed out, so that at 13 Hz operation was normal, with TR 1:1. As frequency increased, the TR increased slowly, and then rapidly at a very strong resonance at about 25 Hz was approached. Rocking motions also became apparent as resonance was approached, this time centered more nearly at the RVM table, so as to add to the motion of the mass. At 24 Hz, TR was 12.5:1; at 25 Hz, the motion was virtually uncontrollable, and the test was terminated at 24 Hz.

Horizontal 90° Direction - Variable Frequency

The variable frequency test was performed over the frequency range or 5 - 23 Hz. The behavior of the test structure was as described above, with the TR reaching a value of 9:1 at 23 Hz.

Horizontal 90° Direction - Endurance

The endurance test was conducted at a frequency of 23 Hz for a period of two hours. No change in TR was noted during this test, and the mounting bolts retained their original torque at its conclusion.

Horizontal 45° Direction - Exploratory

The exploratory test revealed a behavior pattern similar to that found in the Horizontal 90° direction. The test was started at 5 Hz, and 22 Hz, the TR had reached a value of 11.6:1. The test was terminated at this frequency.

Horizontal 45° Direction - Variable Frequency

The variable frequency test was conducted over the range of 5 - 22 Hz. With the greater table excursion, the TR at 22 Hz increased to 18:1.

Horizontal 45° Direction - Endurance

The endurance test was performed at 20 Hz, TR 3.6:1, for two hours. No change in the TR was noted during this period, and the mounting bolts remained at their original torque.

Post-Vibration Test Inspection

The test assembly was disassembled and the chock pads photographed (Figure 19). Their appearance was essentially identical to their original appearance. The test assembly was then reassembled and mounted on the MWSM.

Shock Tests of Test Structure No. 2

The test assembly is shown in Figure 20 as mounted on the MWSM for shock in the Vertical orientation. Pad No. 0 and the adjacent ends of Pads Nos. 4 and 5 are closest to the channels. The total weight on the MWSM anvil table was 2844 lb.

Vertical Shock - Blow 1 - 1-1/4 ft. Drop, 3 in. Travel

No damage was observed. A slight gap was noted between the edge of the mounting ring and the overpour of Pads 1, 6, 7 and 8. No change was noted in this for the other, more severe, blows of the Vertical test, so it is likely that was due to slight misalignment in the most recent reassembly, rather than to relative motion during the blow. A slight loss of torque was noted in all mounting bolts except those through Pads No. 3 and 7, which were about at the center of the mounting plate.

Blow 2 - 2-1/4 ft. Drop, 3 in. Travel

No damage was noted. No change in the gap between the mounting ring and the pads could be detected. The same bolts again loosened very slightly.

Blow 3 - 2-1/4 ft. Drop, 1-1/2 in. Travel

No damage was noted. No change was found in the gap between the mounting ring and the overpour. The same mounting bolts again loosened slightly.

Inclined Shock

The test assembly was then installed in the 30°-Corner Bulkhead (Figure 21, 22) with Pad No. 4 closest to the corner. The total weight on the anvil-table of the MWSM was 4581 lb.

Blow 4 - 2 ft. Drop, 3 in. Travel

No damage was observed. No change was noted in the gap between the mounting ring and the overpour (Pads 1, 6, 7 and 8). All mounting bolts maintained torque.

Blow 5 - 3-1/2 ft. Drop, 3 in. Travel

No damage was observed. The gap between the mounting ring and the overpour of Pads 1 and 8 closed up, while that at Pads 6 and 7 remained unchanged. All mounting bolts maintained torque.

Blow 6 - 3-1/2 ft. Drop, 1-1/2 in. Travel

No damage was noted. No change in the gap status was noted. The mounting bolts passing through Pads No. 0 and 7 loosened slightly.

Extra Blows

The regular specification test series was concluded with Blow 6. As with Test Structure No. 1, additional blows were delivered with the mounting bolts loosened. Their torque was reduced from 150 ft.-lb. to 12 ft.-lb., the torque required to grip the lock-washers firmly without closing them appreciably. The test assembly was also rotated 180° in the 30°-Corner Bulkhead, bringing Pad No. 8 closest to the corner.

Blow 7 - 3-1/2 ft. Drop, 3 in. Travel

No damage was found. The gap in Pad No. 7 closed, leaving only that in Pad No. 6.

Blow 8 - 3-1/2 ft. Drop, 1-1/2 in. Travel

No damage noted. The gap in Pad No. 6 also closed up.

Blow 9 - 3-1/2 ft. Drop, 3 in. Travel

For this blow, the mounting bolts were loosened completely, then tightened finger-tight. With this condition, a triangular segment chipped out of Pad No. 2 from the outside of the bolt-hole adjacent to Pad No. 3 (Figures 23, 24).

Post-Shock Test Inspection

The test assembly was then taken apart and the top (Figure 23) and bottom (Figure 24) surfaces of the chock pads photographed. With the exception of the small piece chipped out of Pad No. 2, the condition of the pads seems little changed by the shock test. The

damage noted would cause a miniscule decrease of load-bearing area, and would not be likely to impair alignment of a mounted item. The affected pad conceivably could rotate about the bolt through the intact hole, but with this chock pad configuration could do so only to a small degree.

Discussion and Conclusions

The chock pads of both the test structures employed in the tests reported here were essentially unaffected by vibration test, while the shock tests revealed only a slight tendency for the mounting bolts to untorque when the structures were mounted on the flexible channels, and some motion of the pads of Test Structure No. 2 in the Inclined orientation. Damage to the pads was found only on the extra blows, where the structures were in the Inclined orientation with loosened mounting bolts, and in both cases occurred in pads whose mounting bolts were located close to the outside edge. In neither case was the damage observed of a nature which would impair load-carrying capacity or item alignment, although a slightly different crack trajectory in the case of Test Structure No. 1 might have resulted in the total loss of the pad. The test structures were designed to present rather severe demands to the chocking arrangement from their large overturning moments, unfinished mounting ring surfaces, and highly non-uniform pattern of loading around the mounting rings. The epoxy chocking seemed to perform well, at least with the pad configuration employed.

Auxiliary tests indicated no great effect of test temperature on the relevant physical properties of the epoxy material except a slight drop in Izod impact strength at low temperatures. This would indicate a potential for greater susceptibility to cracking at low temperatures.

The behavior of the epoxy material in regard to creep was not investigated directly, but an indication was obtained fortuitously by a test machine breakdown. Vibration tests of Test Structure No. 1 were postponed for several months while the RVM was rebuilt, so that the test assembly sat fully torqued for this period following assembly after the initial inspection of the newly-cast pads. No decrease in mounting-bolt torque could be detected following this.

A factor not investigated which could affect the shock and vibration performance is the influence of prolonged maintenance at extremely high or low temperature. This could also be a factor in creep behavior of the epoxy material. Also, it is possible that a more flexible mounting situation than that employed here could result in more extensive cracking of the pads. It would seem a good practice to divide the chocking system into fairly small segments, as done here, in order to limit the propagation of such cracks as may occur.

A final factor which should be borne in mind is that a chock arrangement of any description constitutes an elastic element between the mounted item and the ship structure, and its possible effects on the item's dynamics should be considered.

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2. MIL-STD-167-1 (SHIPS), "Military Standard Mechanical Vibrations of Shipboard Equipment (Type I - Environmental and Type II - Internally Excited)," NAVSEC 6124, May 1974.

3. E. W. Clements, "Shipboard Shock and Navy Devices for its Simulation," NRL Report 7396, 14 July 1972, DDC # AD746, 444.

4. ASTM D 695-69, "Standard Test Method for Compressive Properties of Rigid Plastics," American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

5. ASTM D 256-73, "Standard Test Methods for Impact Resistance of Plastics and Electrical Insulating Materials," American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

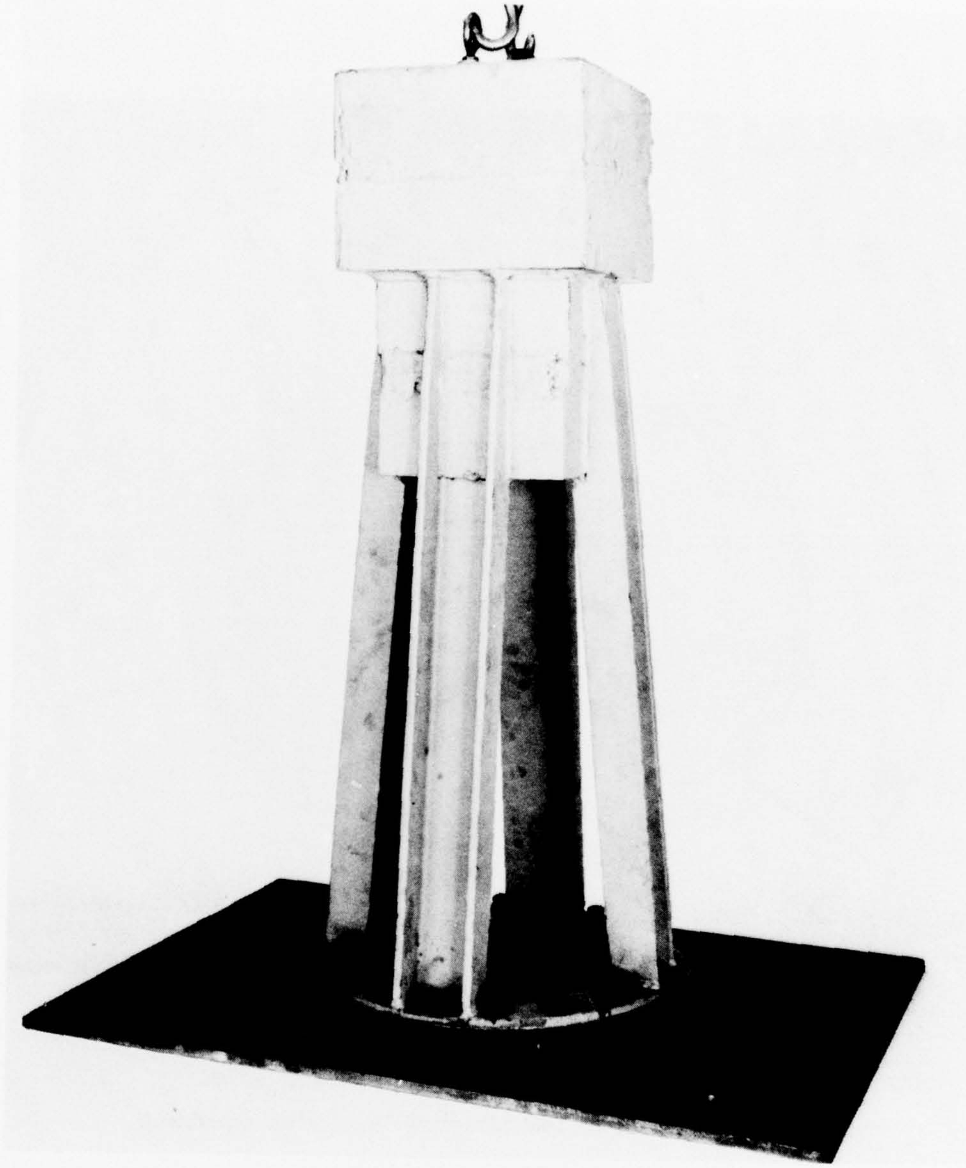

Fig. 1 — Test Structure No. 1 after dams had been removed from the cured chocks

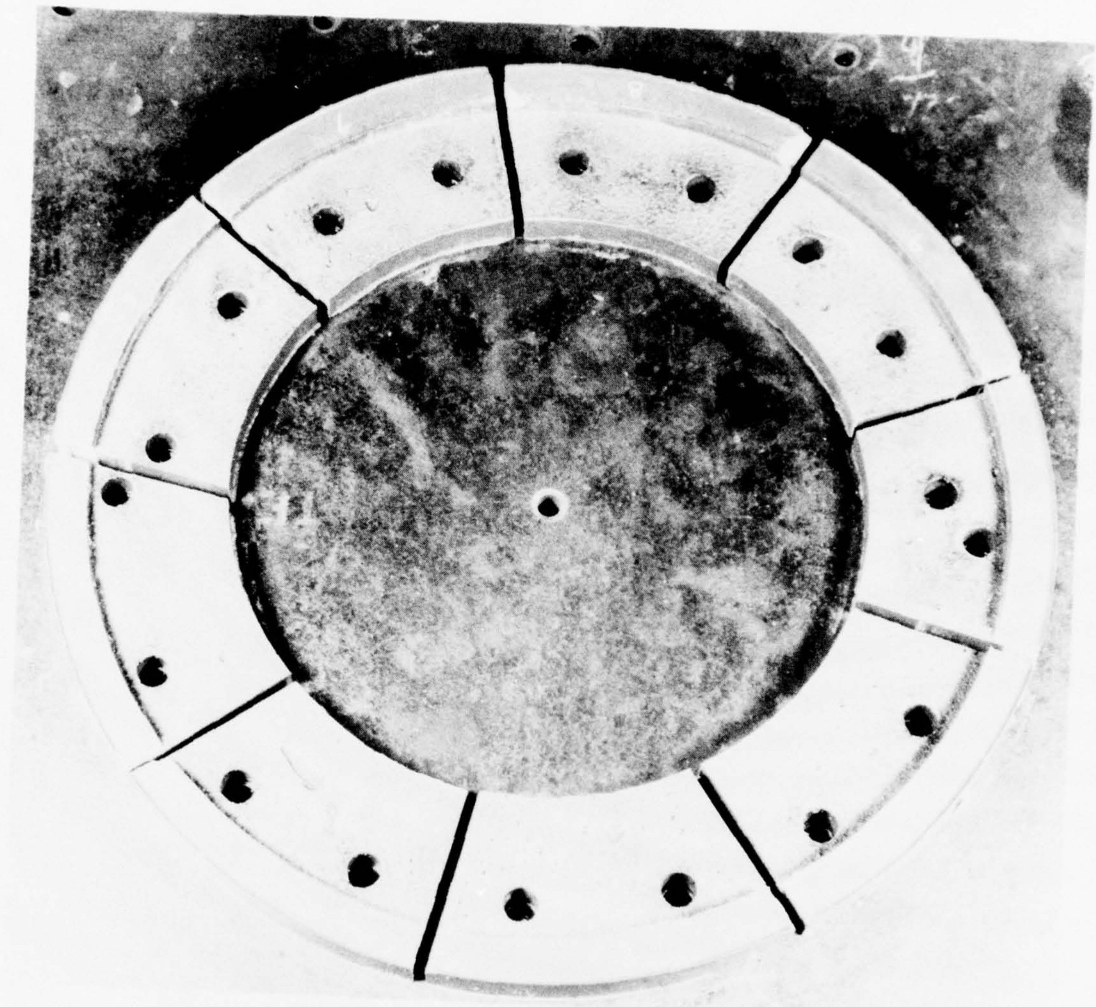

Fig. 2 — Chock pads of Test Structure No. 1 after separation

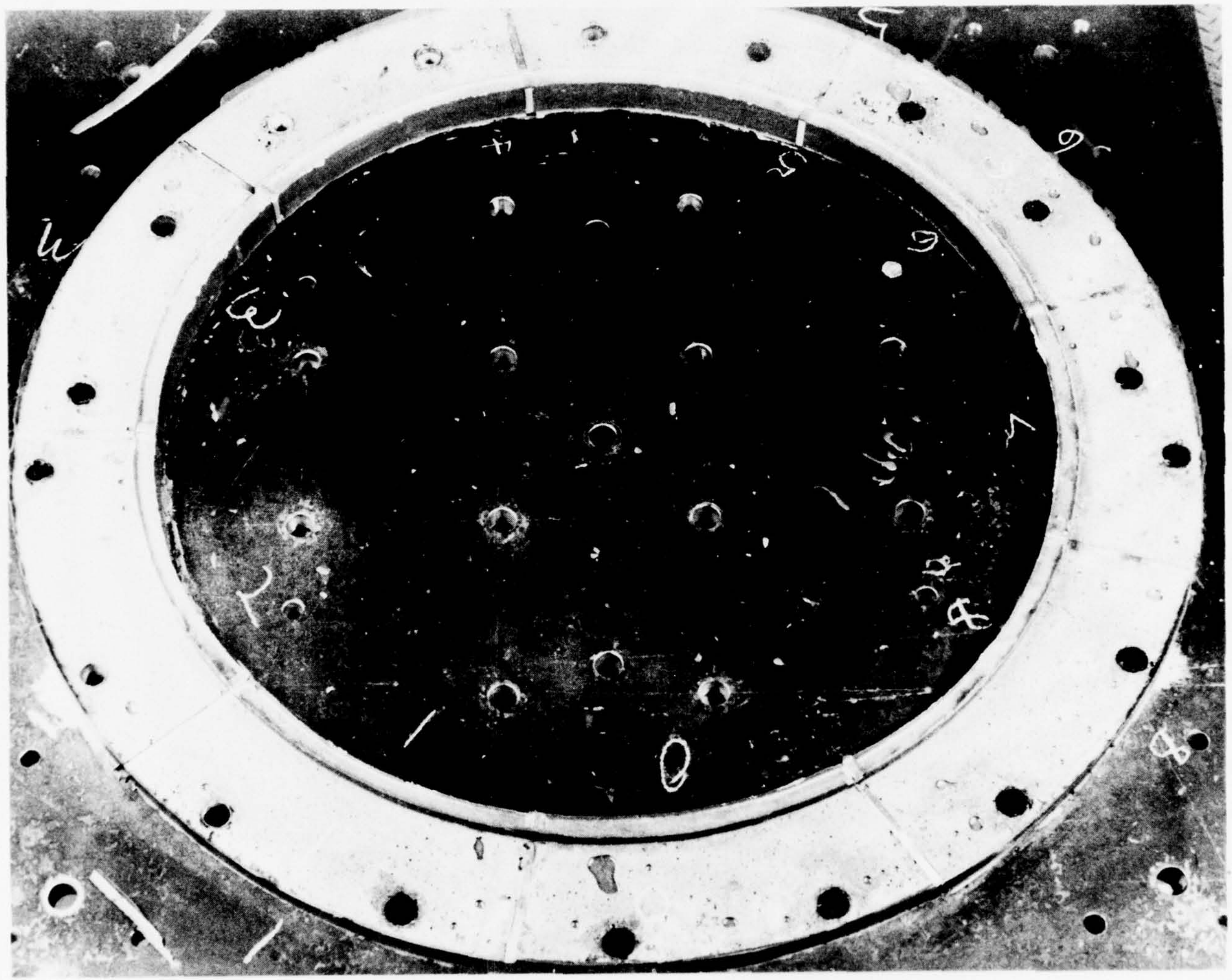

Fig. 3 — Chock pads of Test Structure No. 2 after removal from the test assembly, before separation

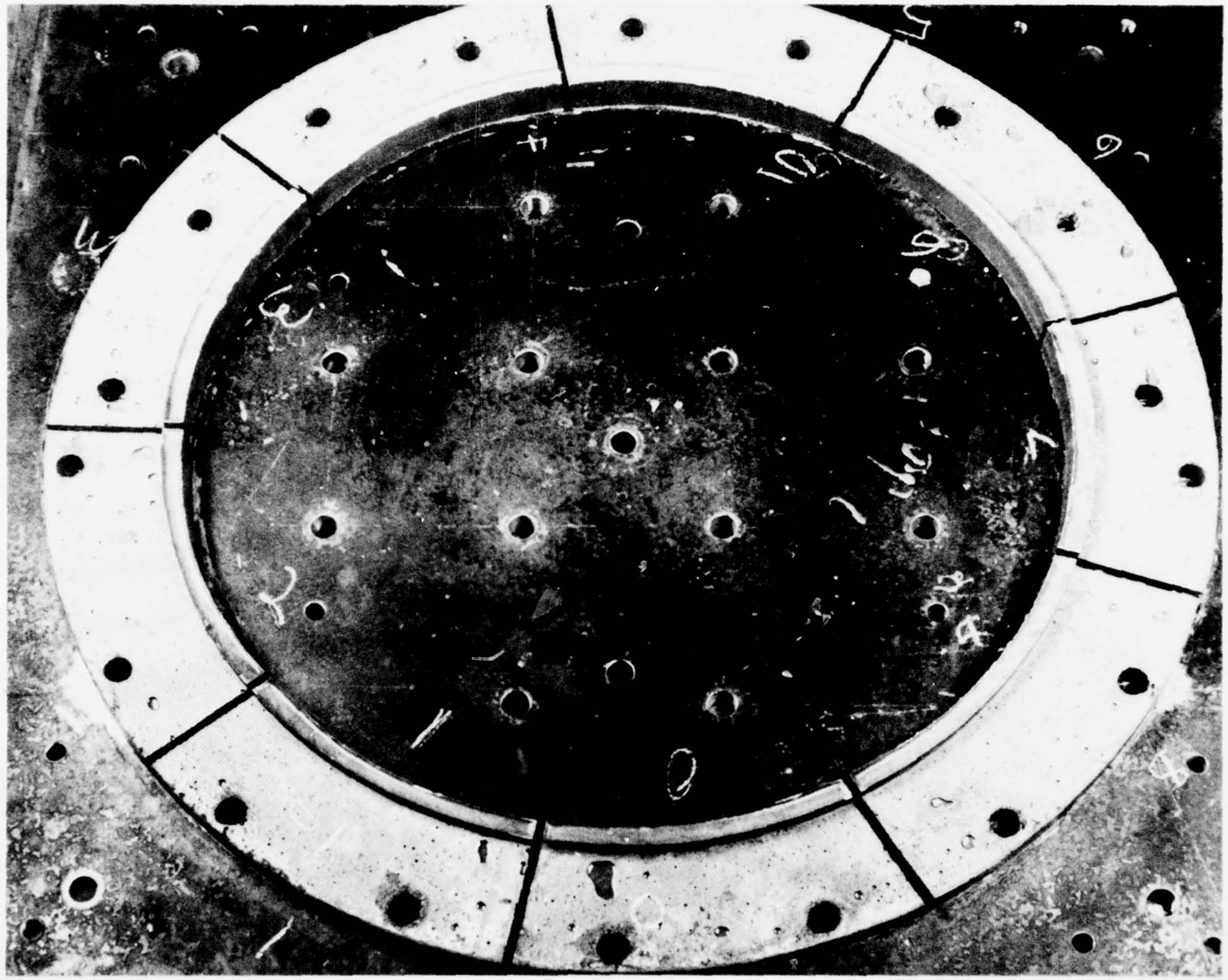

Fig. 4 — Top surface of the chock pads of Test Structure No. 2 after separation

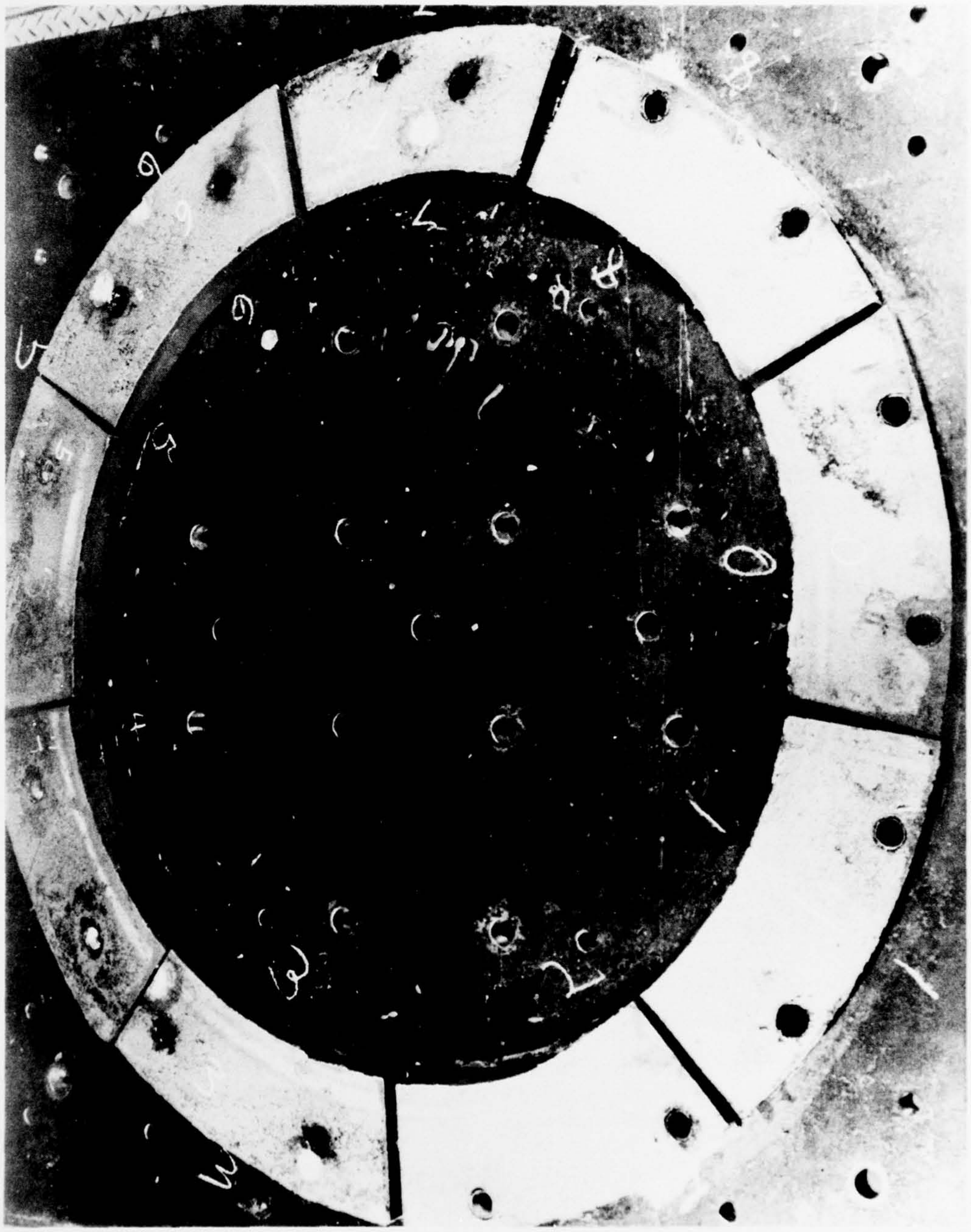

Fig. 5 — Bottom surface of the chock pads of Test Structure No. 2 after separation

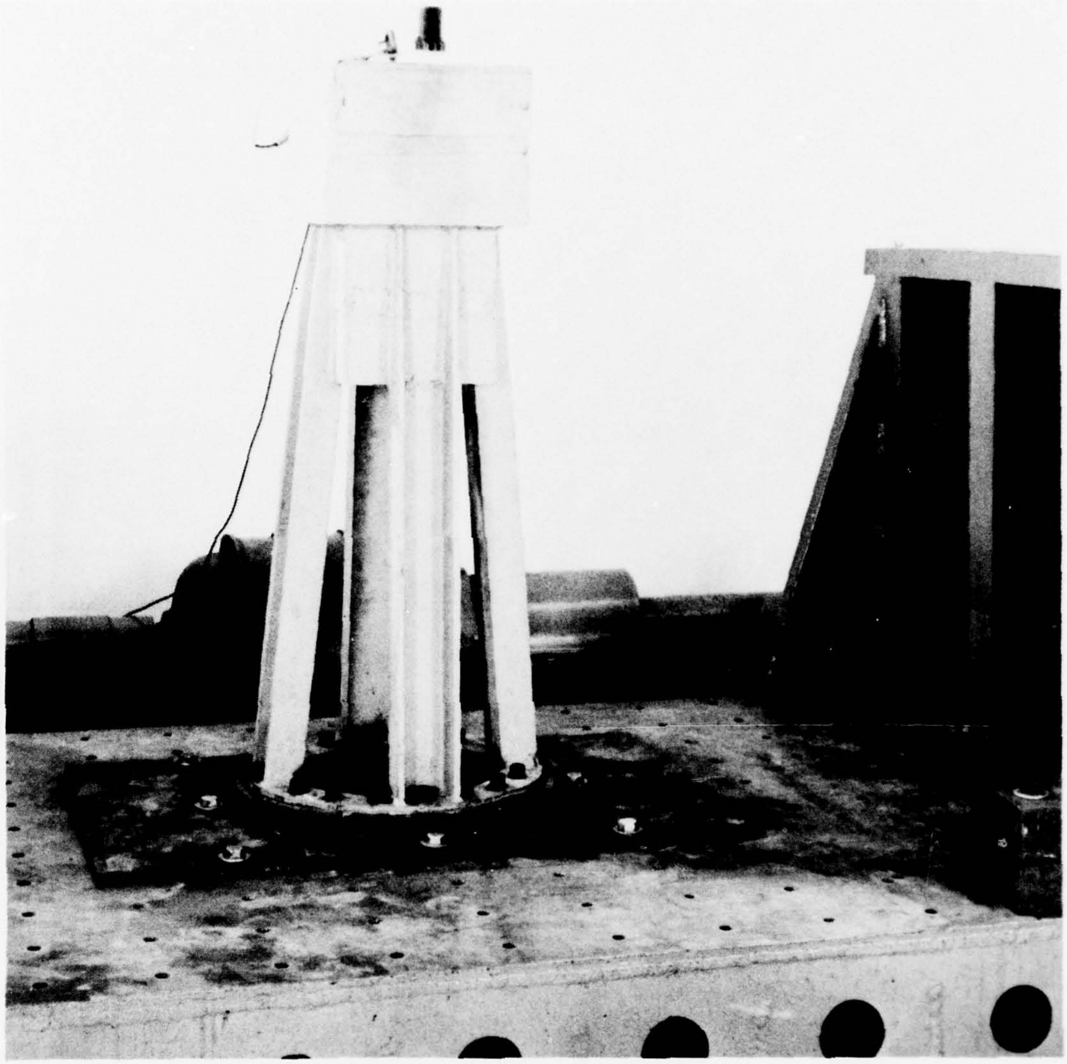

Fig. 6 — Test Structure No. 1 mounted on the RVM for vibration in the Vertical direction. The black cylinder at the top of the mass is a transducer for measuring the motion at that point.

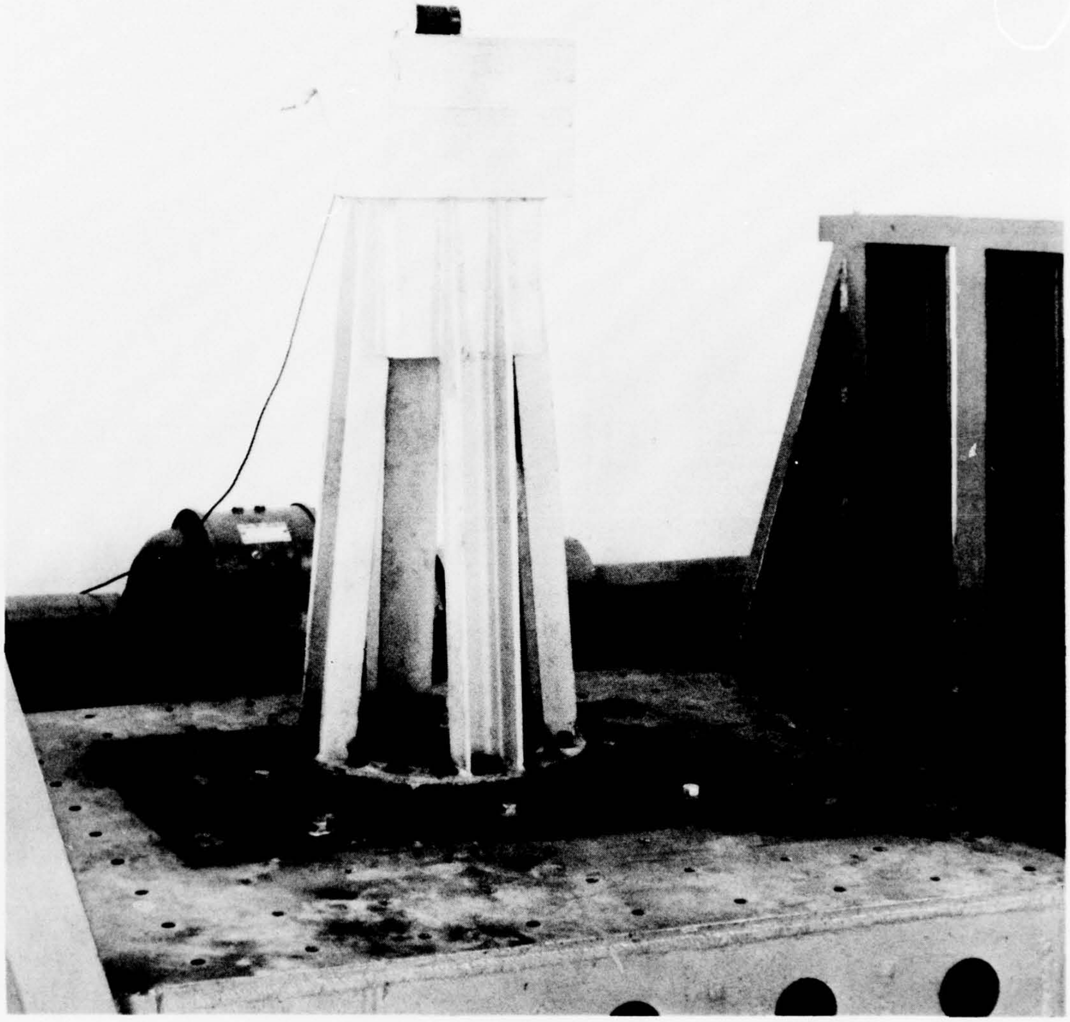

Fig. 7 — Test Structure No. 1 mounted on the RVM for vibration in the Horizontal 90° direction

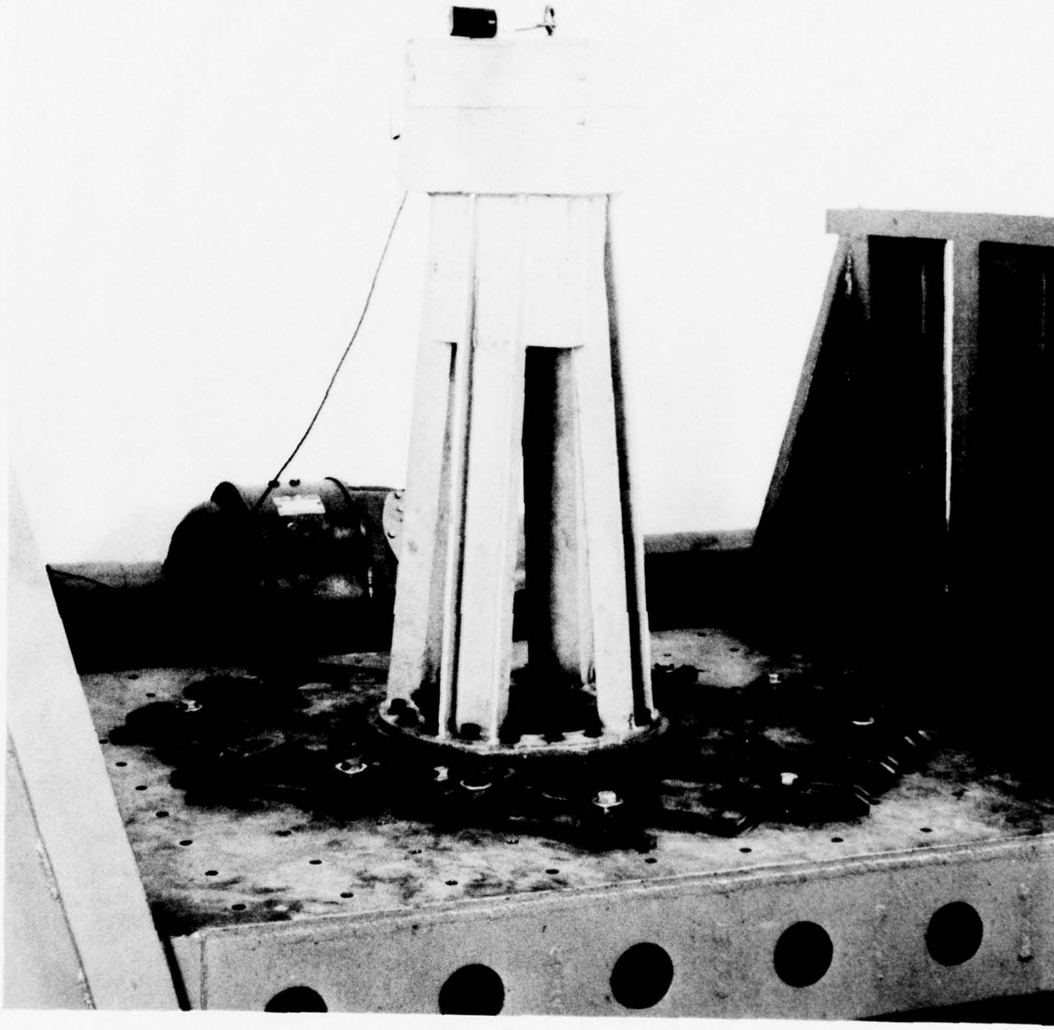

Fig. 8 — Test Structure No. 1 mounted on the RVM for vibration in the Horizontal 45° direction

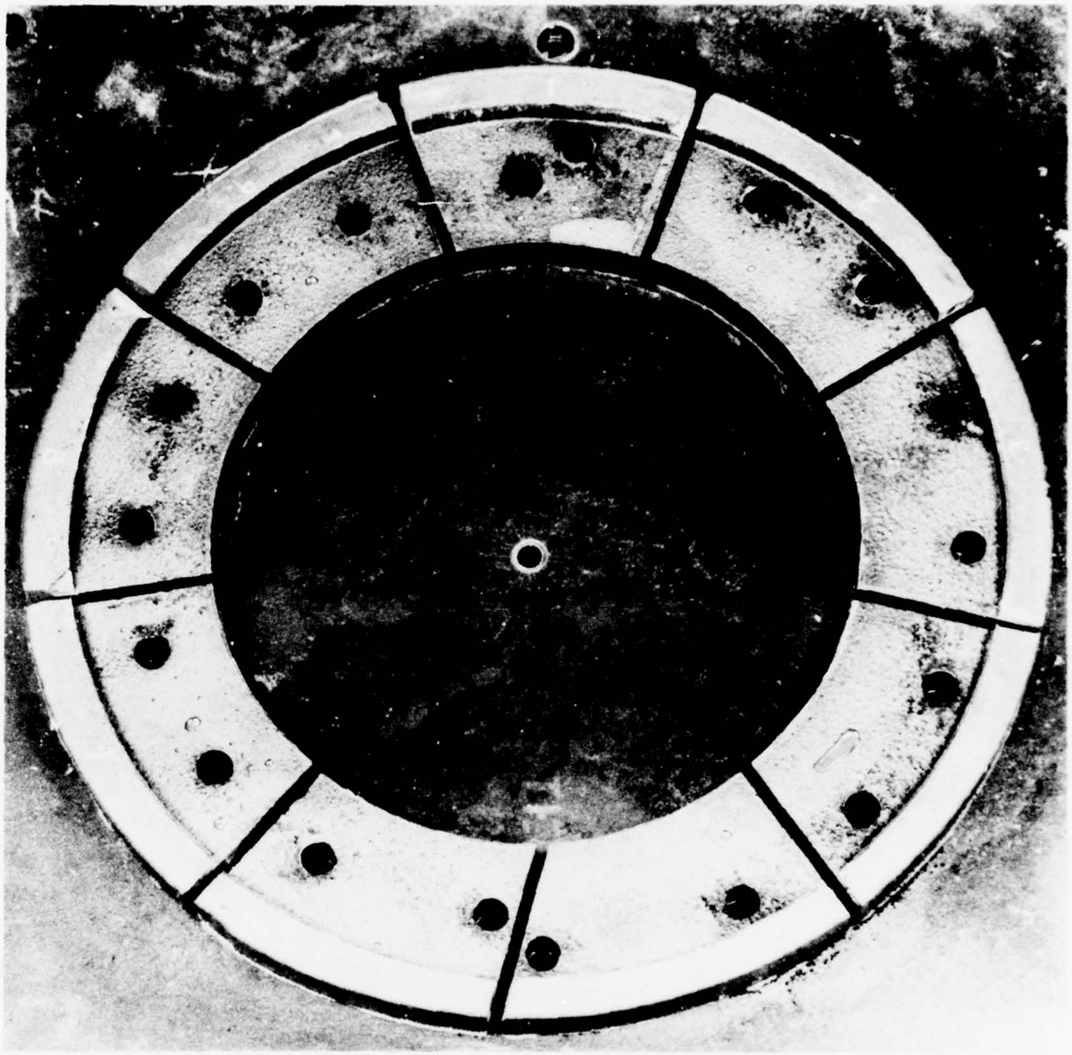

Fig. 9 — Top surface of the chock pads of Test Structure No. 1 following vibration test

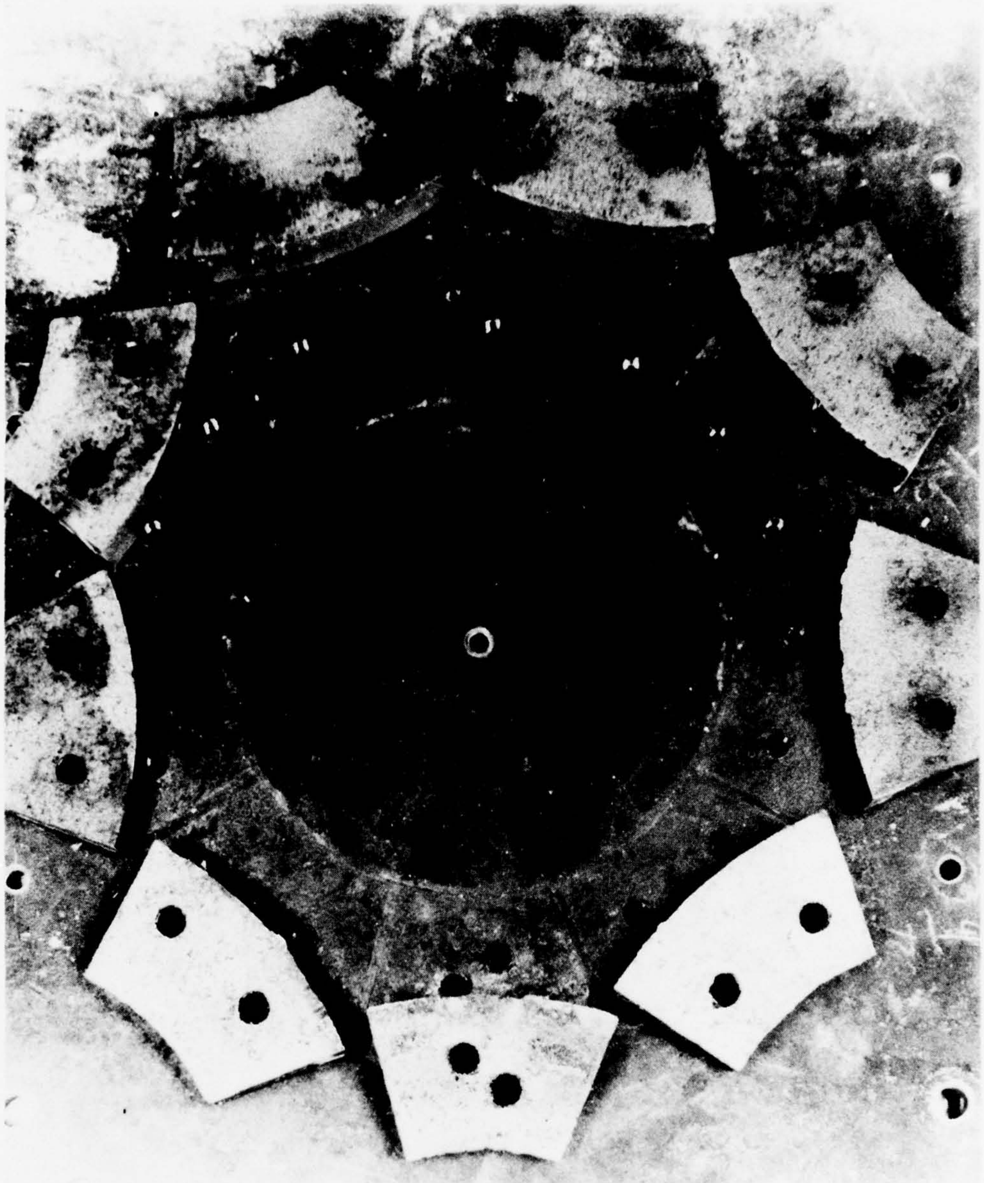

Fig. 10 — Bottom surface of the chock pads of Test Structure No. 1 following vibration test

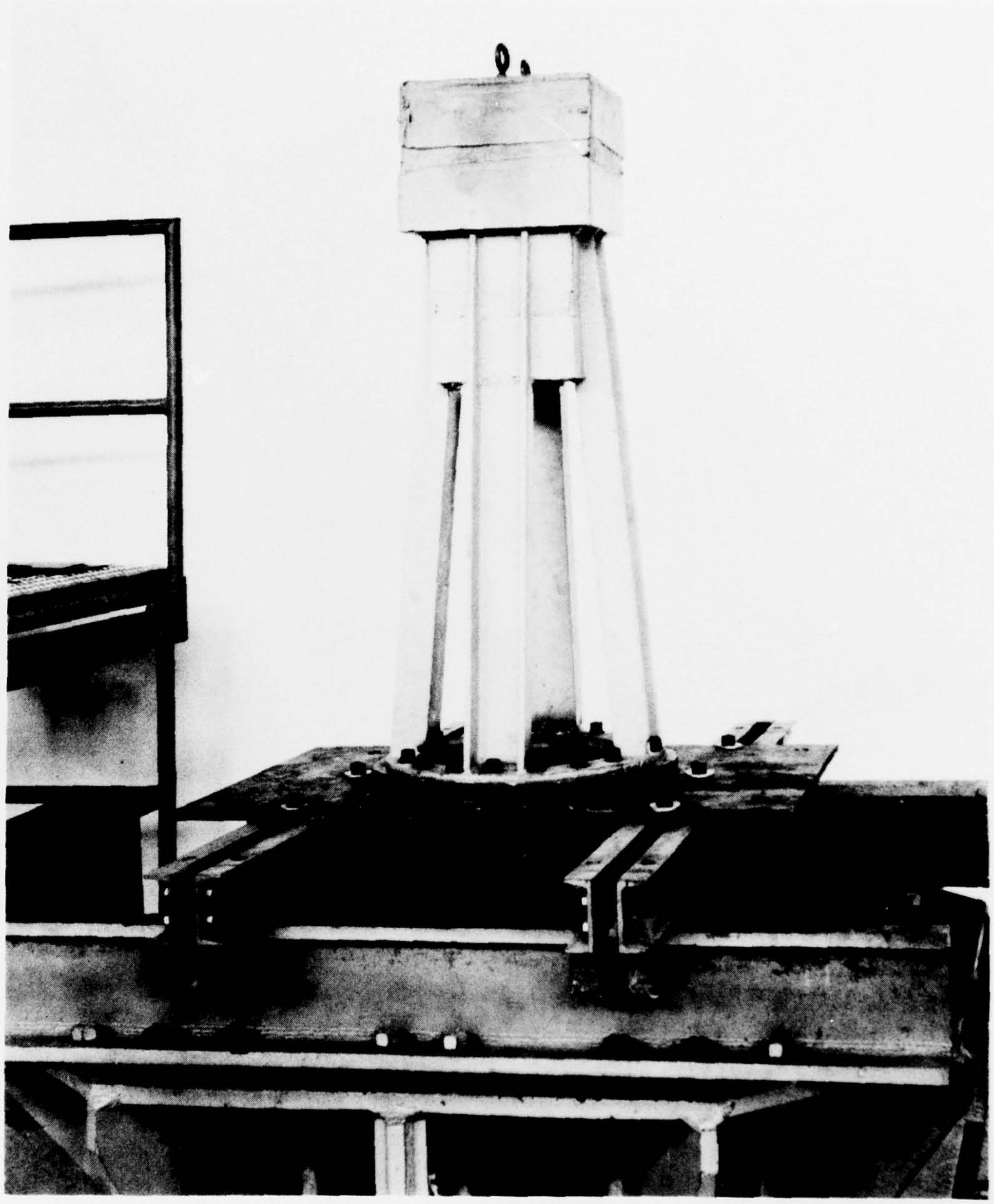

Fig. 11 — Test Structure No. 1 mounted on the MWSM for Vertical Shock

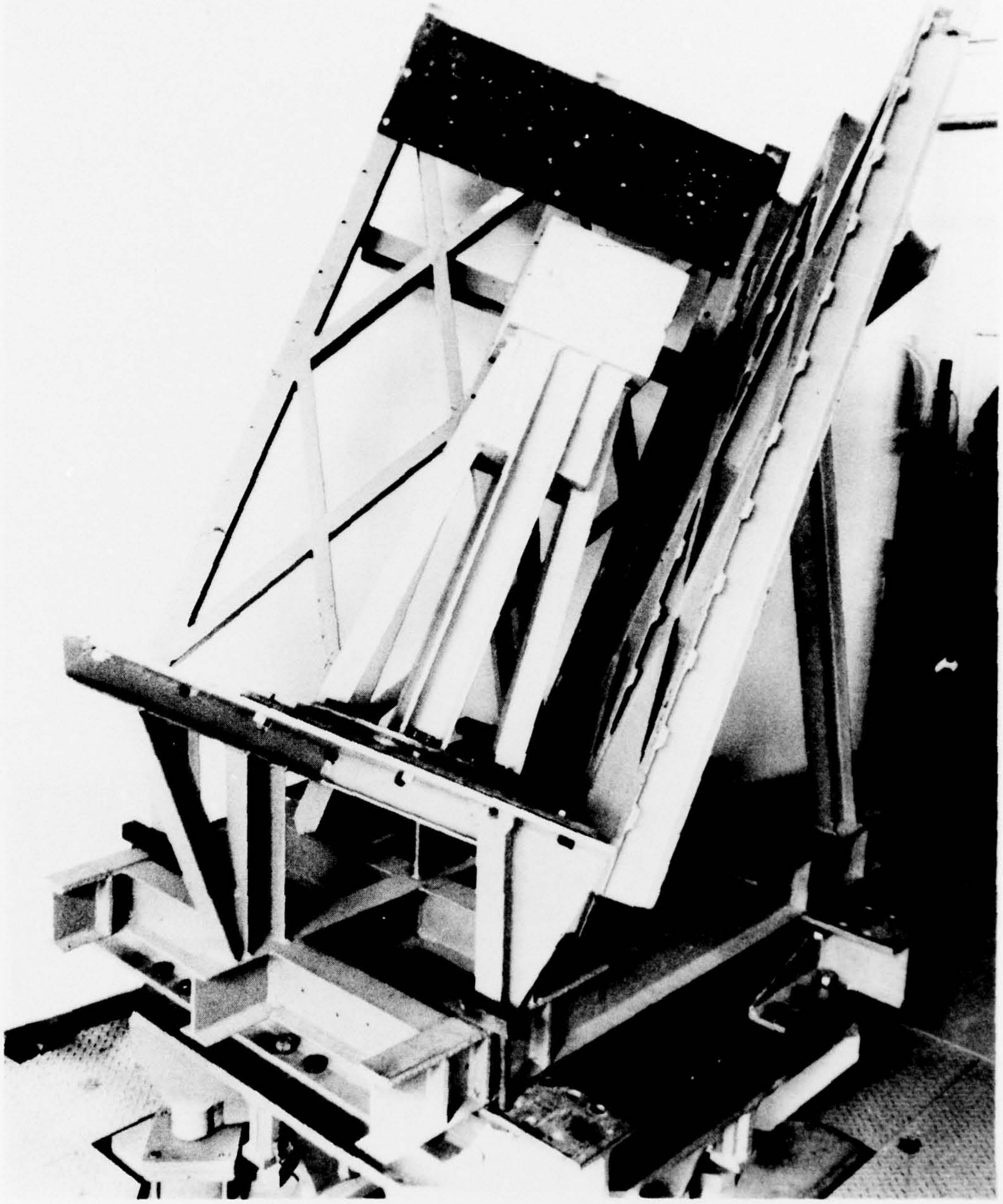

Fig. 12 — Test Structure No. 1 mounted on the MWSM in the 30°-Corner Bulkhead for Inclined Shock

Fig. 13 — Damage from shock. After the regular shock test of Test Structure No. 1 had been completed, two additional blows were delivered with the mounting bolts loosened. A section of Pad No. 3 broke off and slid out from under the mounting ring. It may be seen resting against the heads of the row of bolts securing the mounting plate to the 30°-Corner Bulkhead.

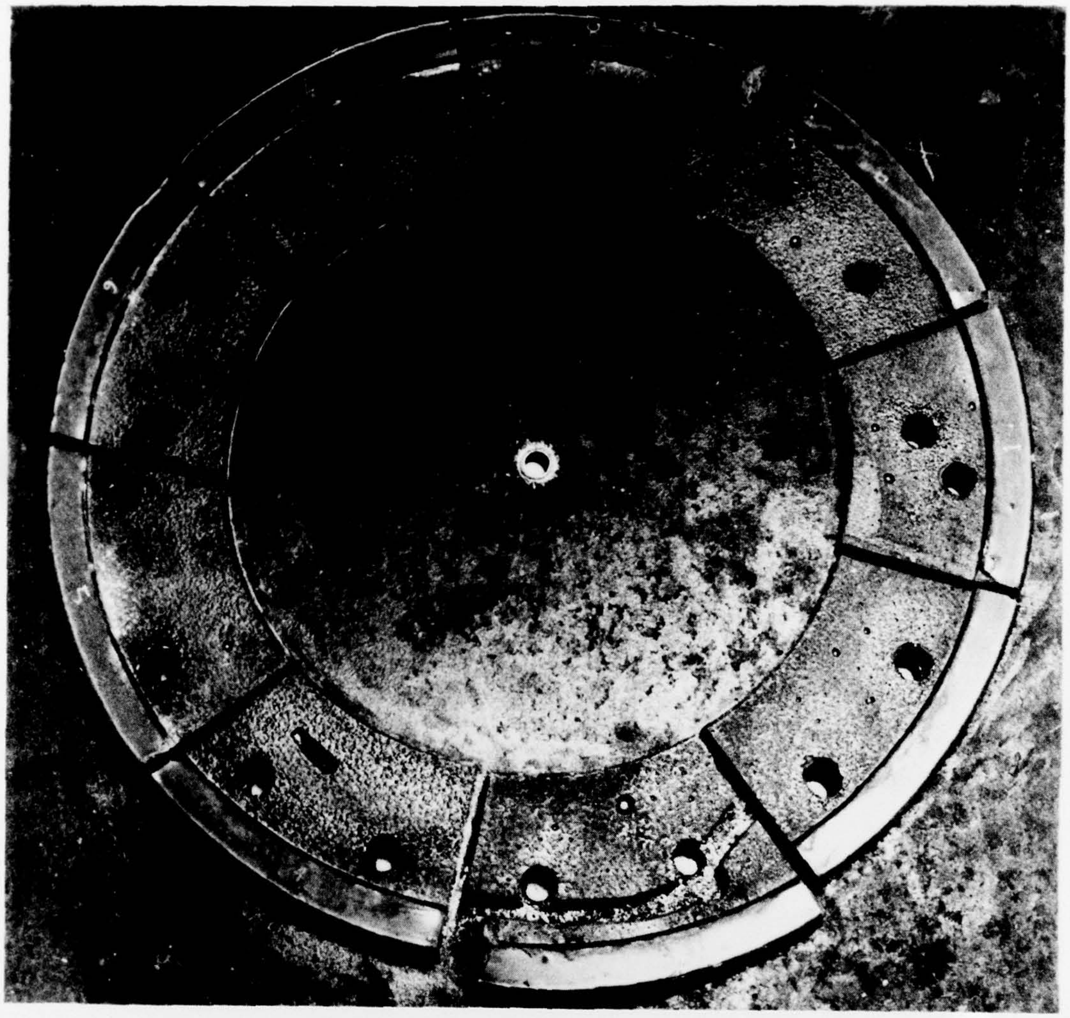

Fig. 14 — Top surface of the chock pads of Test Structure No. 1 following shock and vibration testing. Note the broken Pad No. 3.

Fig. 15 — Bottom surface of the chock pads of Test Structure No. 1 after shock and vibration testing

Fig. 16 — Test Structure No. 2 mounted on the RVM for vibration in the Vertical direction

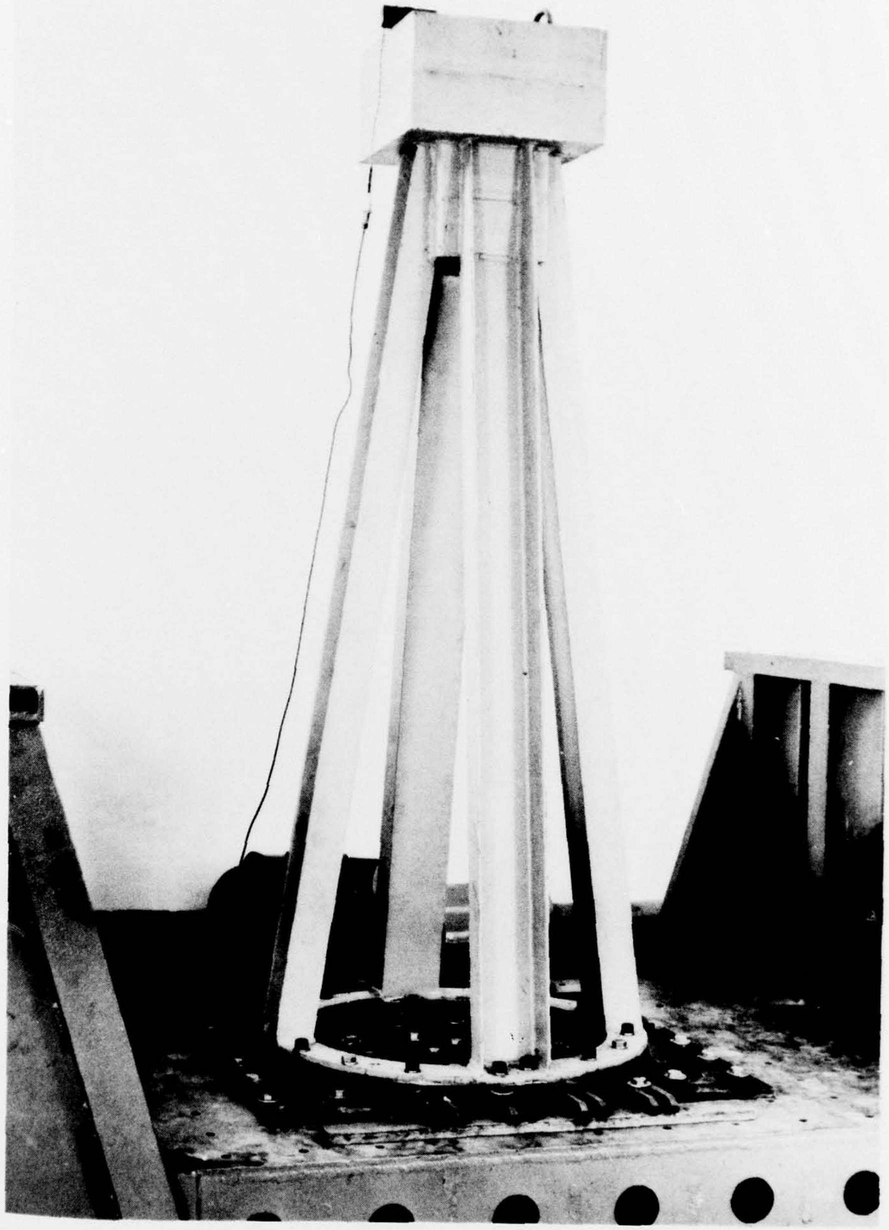

Fig. 17 — Test Structure No. 2 mounted on the RVM for vibration in the Horizontal 90° direction

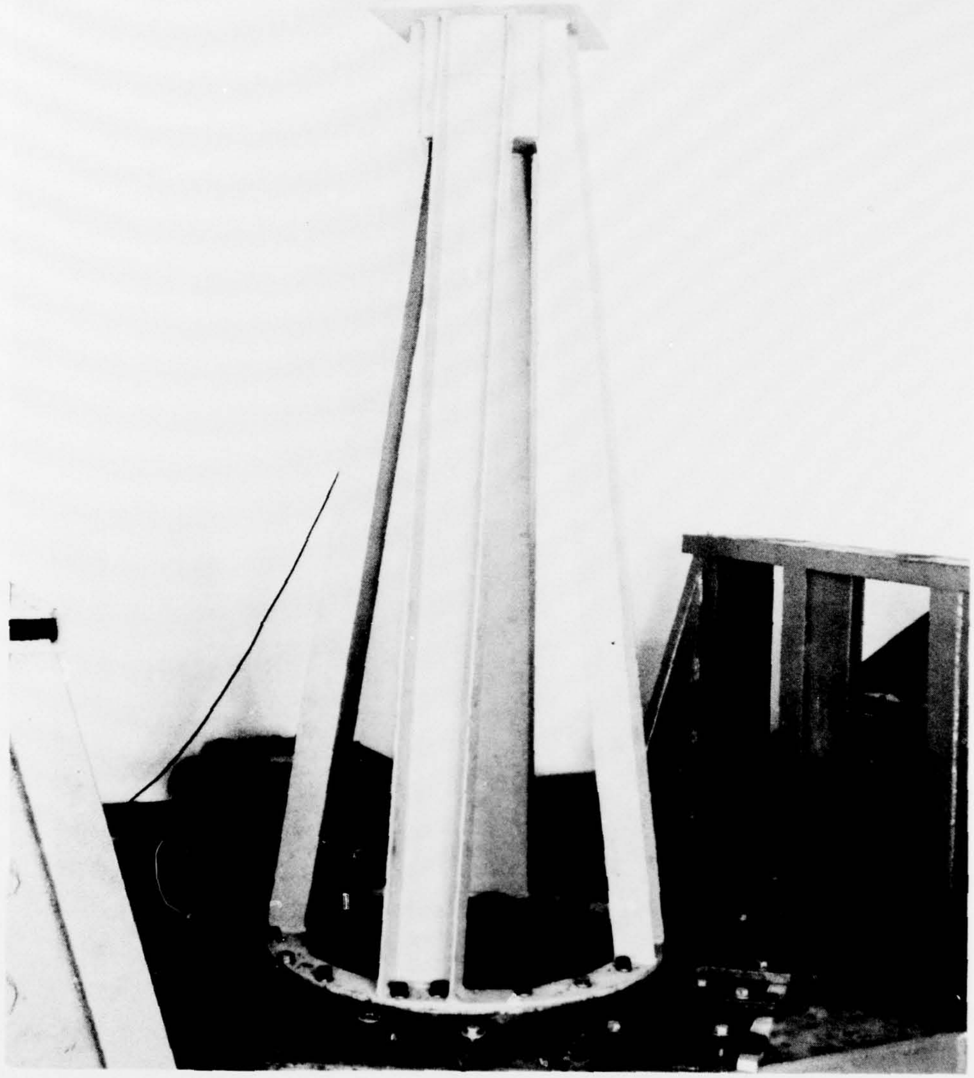

Fig. 18 — Test Structure No. 2 mounted on the RVM for vibration in the Horizontal 45° direction

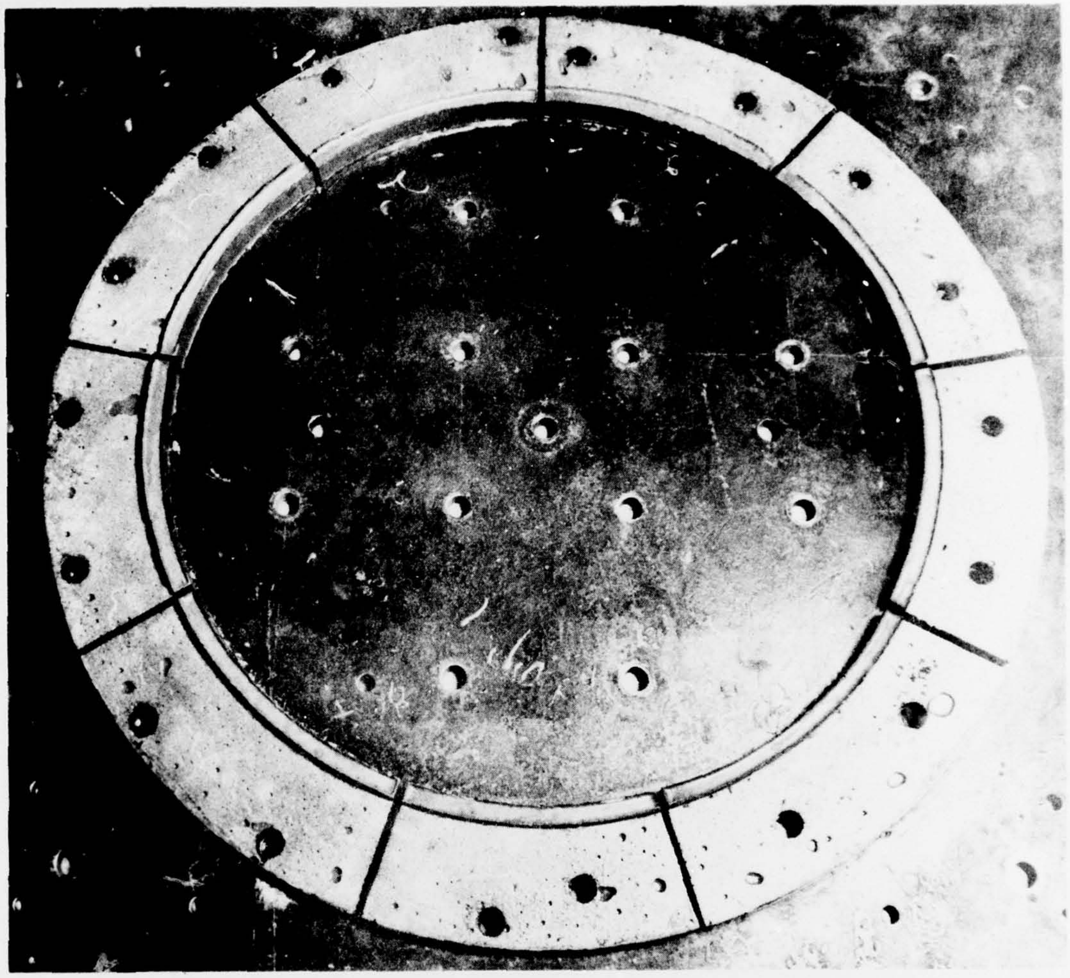

Fig. 19 — Chock pads of Test Structure No. 2 after vibration test

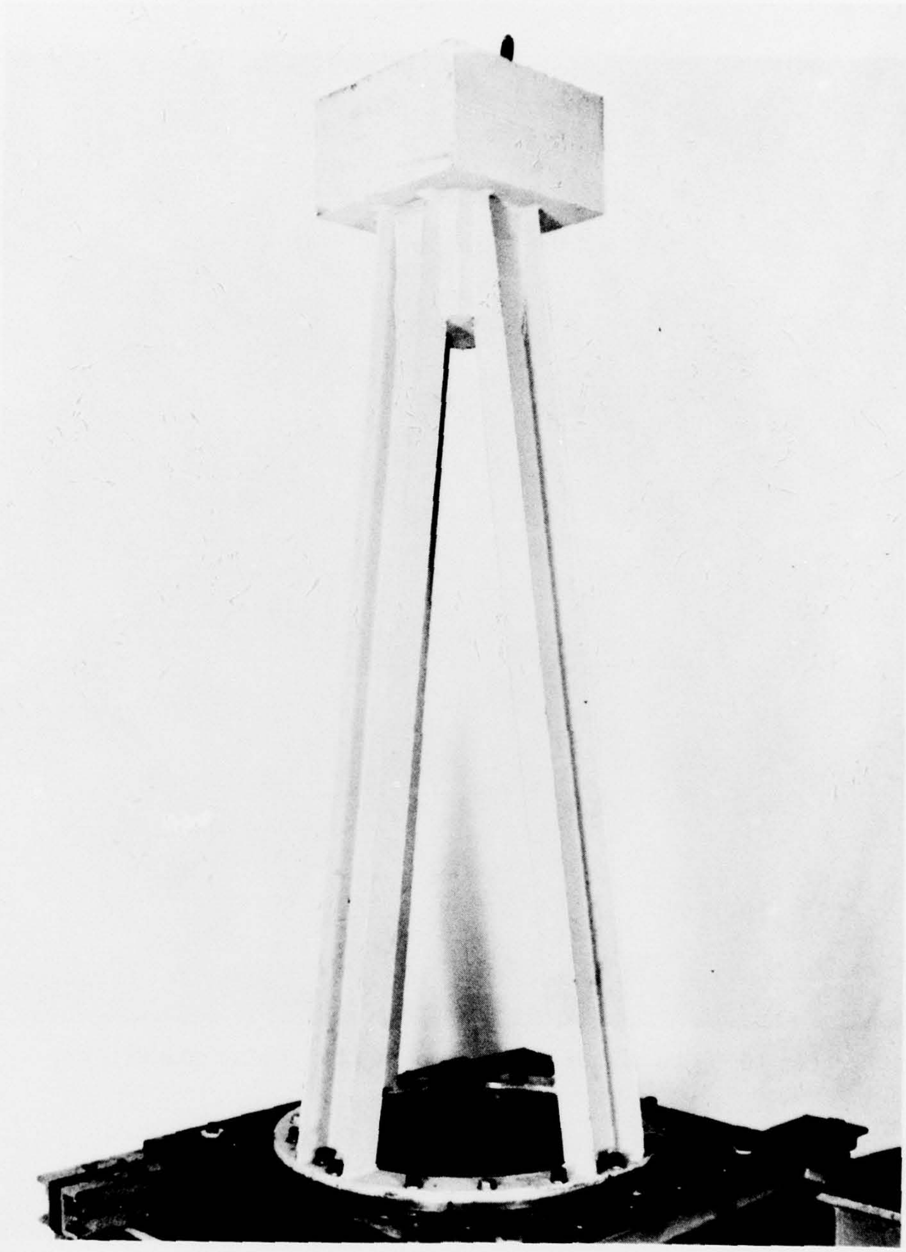

Fig. 20 — Test Structure No. 2 mounted on the MWSM for Vertical Shock

Fig. 21 — Test Structure No. 2 mounted on the MWSM in the 30°-Corner Bulkhead for Inclined Shock

Fig. 22 — Test Structure No. 2 mounted on the MWSM in the 30°-Corner Bulkhead for Inclined Shock

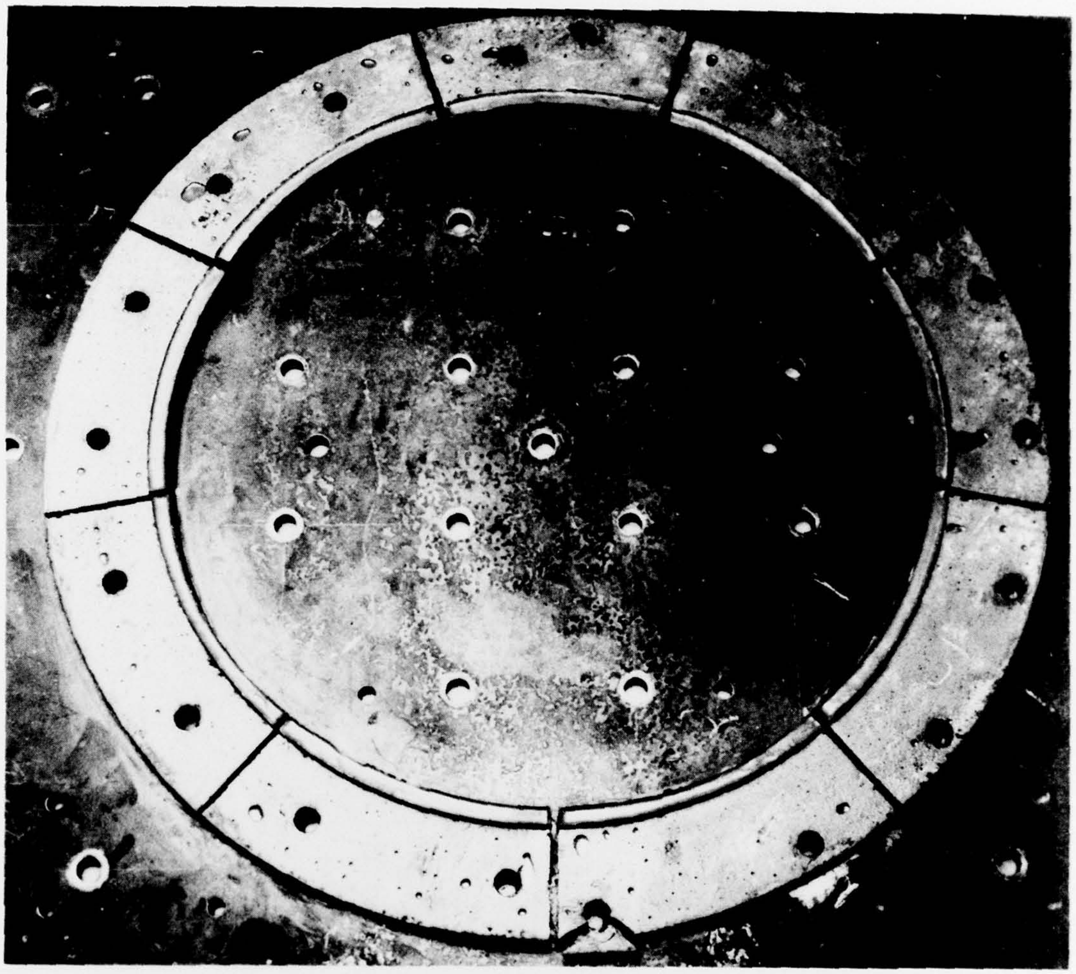

Fig. 23 — Top surface of chock pads of Test Structure No. 2 after shock and vibration tests. Note chip broken out of Pad No. 2 during extra blows

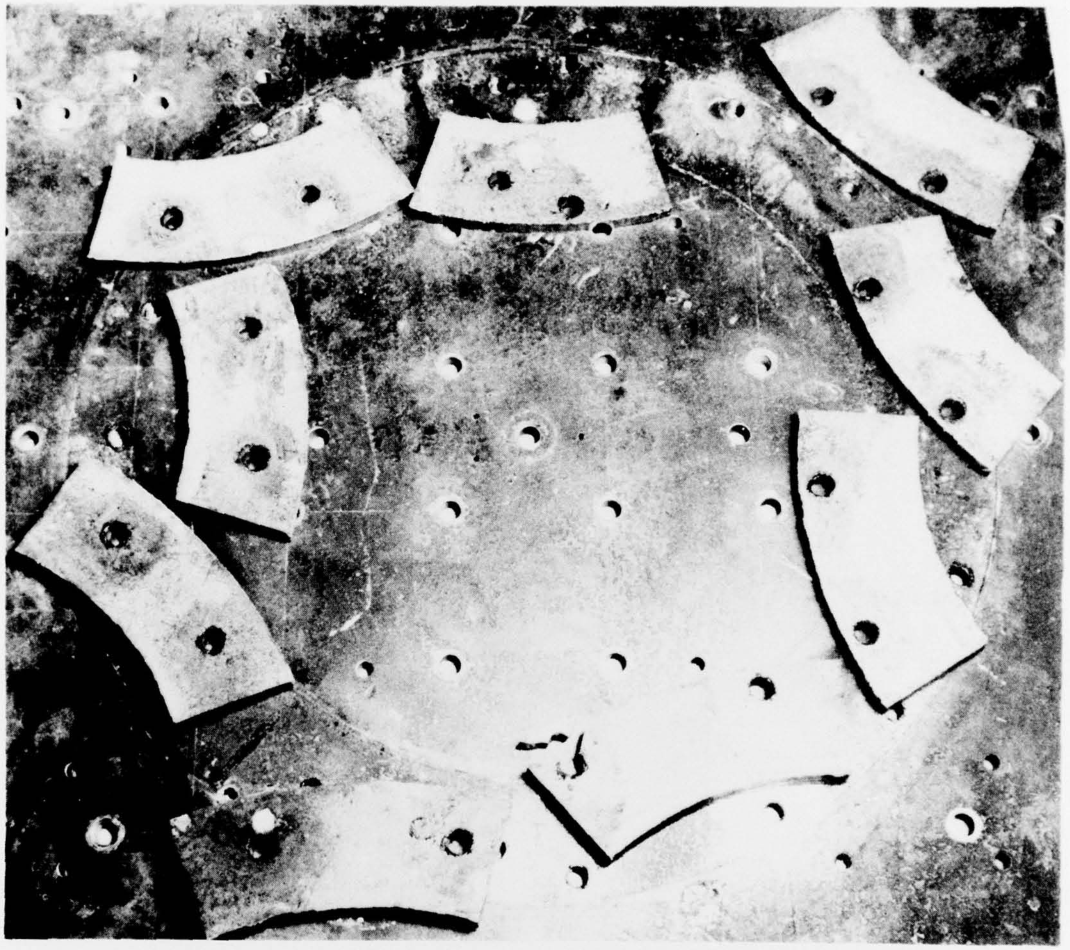

Fig. 24 — Bottom surface of chock pads of Test Structure No. 2 after shock and vibration tests

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